Guarding the border: watchtowers of the Nasrid Kingdom of Granada. Characterization and vulnerability assessment

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ABSTRACT: The Islamic Nasrid kingdom of Granada occupied the mountainous areas of the south-eastern of the Iberian Peninsula. The frontier between the Nasrid kingdom and the Christian kingdom of Castile from 1232 to 1492 was controlled by an extensive network of watchtowers built by Nasrid through the provinces of Granada, Malaga, Almeria and the eastern parts of Jaen, Cordoba and Cadiz. They allowed to control this frontier stablishing visual communication between them and the Nasrid centre at the Alhambra citadel. Even protected by Spanish Heritage law, many of these medieval towers and their cultural landscapes are in severe risk because of anthropic action as well as natural deterioration. Within the framework of the R&D project called 'Las atalayas que defendieron el reino nazarí de Granada. Análisis y documentación científica (Nazalaya)", the towers are being studied. As a complement of planimetry obtained by procedures as photogrammetry or terrestrial laser scanning (TLS), complete architectural surveys using non-destructive techniques are being performed as part of the analysis to obtain a global description of construction systems used.

1 INTRODUCTION

Among the rich Cultural Heritage and Artistic Heritage that Andalusia possesses, stands out the one that is constituted by the network of preserved fortifications, one of the most important patrimonial asset in the world due to the high density of defensive architecture preserved, as a consequence of the border character and as a place of confluence between civilizations that the south of the Iberian Peninsula has always had.

The Islamic Nasrid kingdom of Granada occupied the mountainous areas of the south-eastern of the Iberian Peninsula (Arié, 1992). The frontier between the Nasrid kingdom and the Christian kingdom of Castile from 1232 to 1492 was controlled by an extensive network of watchtowers built by Nasrid (Argüelles Márquez, 1995). They allowed to control this frontier stablishing visual communication between them and the Nasrid centre at the Alhambra citadel (Acién Almansa, 1989). Due to its frontier condition most of them are disperse through the provinces of Granada, Malaga, Almeria and the eastern parts of Jaen, Cordoba and Cadiz as an essential and indivisible component of natural environment. Even being this military architecture protected by Spanish Heritage law, many of these medieval towers and their cultural landscapes are in severe risk because of anthropic action as well as natural deterioration.

With the fundamental purpose of avoiding this deterioration, a global study is proposed to simultaneously allow to increase the existing information now about them, as well as to clearly identify the risks these elements are exposed. In this way the global study of this large network of defensive towers has been raised in the framework of the research project 'The watchtowers who defended the Nasrid kingdom of Granada. Analysis and scientific documentation (Nazalaya)' (HAR2016-79689-P) financed by the Ministry of Economy, Industry and Competitiveness of Spain. The number of elements is listed in table 1 and located in figure 1.

Table 1. Set of towers in better conditions.

Setting	Watchtowers	Towers related to farmhouses
Mountain range of Ronda - Málaga	9	5
Sierra of Antequera	4	-
Poniente Granada and Eastern mountains	23	20
Sierra de Segura and Altiplano de Guadix y Baza	33	9
Sierra de María, Puerto Lumbreras and Almanzora Valley	13	-
	82	**34**

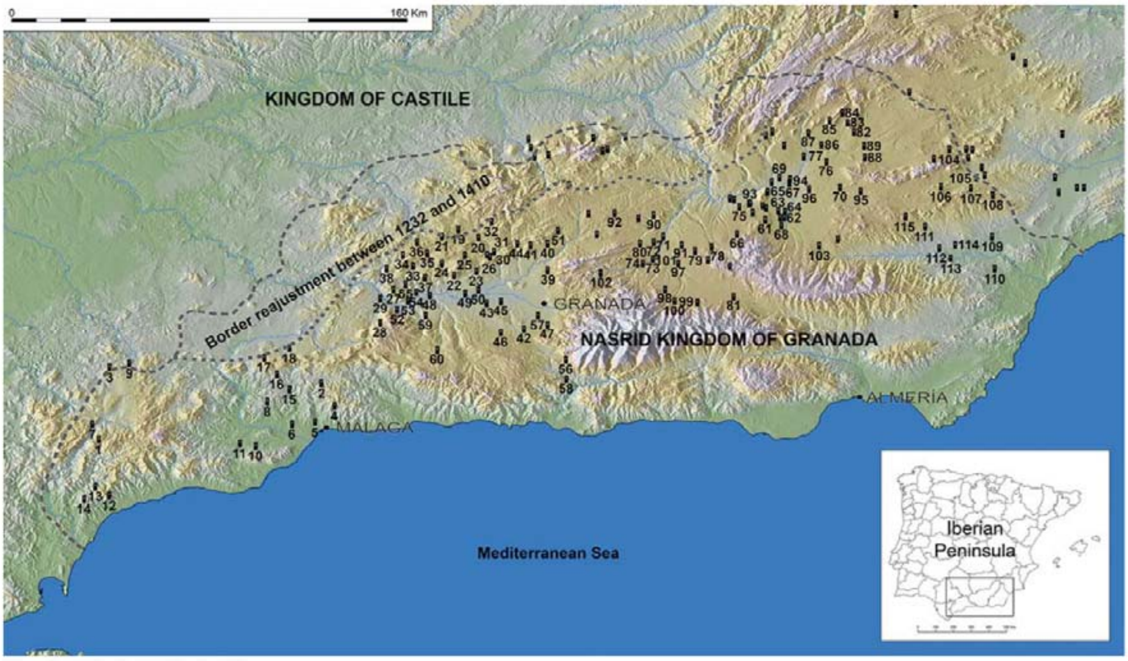

Figure 1. Location of defensive towers in the Nasrid Kingdom of Granada

The general objectives to be achieved during the development of the project are the following:

- To create a global comprehensive knowledge of the military buildings studied through the development of a complete graphic and cartographic inventory, promoting the analysis of this extended heritage from the historical, structural, archaeological, geotechnical and landscape points of view.
- Investigate the construction techniques in masonry and earthen walls of these military buildings, as well as their evolution in the transition from the Middle Ages to the Modern Era.
- Study of the criteria for the implementation of this type of military architecture in the Nasrid kingdom.
- Study of the characteristics that define the Cultural Landscapes in which these fortifications are located. Nowadays these elements contribute to enhance the values of the landscape.
- Understand the processes of degradation of these structures over time, analysing their current conservation status. Based on this diagnosis, necessary measures to guarantee its survival and its legacy to future generations will be proposed.
- Proposal of a methodology to establish measures, priorities and to define the intervention criteria. This imply to generate a protocol on these assets and their landscapes, complying with the requirements formulated by the Spanish and Andalusian Historical Heritage Laws, guaranteeing at the same time the requirements established by the Spanish Technical Code.
- Develop lines of dissemination for the fortresses under study by generating a heritage management database using Geographic Information Systems (GIS), making this information available in Open Data for researchers, as well as for any interested person.

To achieve these objectives, the initial step is directed to carry out exhaustive surveys of each of the towers included in the project. These include the generation of detailed plans (level plans and sections) as well as elevations and external perspectives using the technique of photogrammetry. These representations have not been limited exclusively to the tower as a valuable object. Additionally, it has been included the necessary information of the surroundings (Figure 2) allowing to assess them as landscape elements capable of providing an additional value (Rössler, 2006).

Figure 2. Planimetry of Romeral watchtower in Baza (Granada) using photogrammetry techniques

Landscape, which often finds in the defensive patrimony preserved one of its main centres of attraction, have currently an important heritage value that contributes and can enhance the economic and social development of municipalities in Andalusia where these elements are located

(Longstreth, 2008). Besides, this analysis from a wider territorial vision that exceeds the geographical boundaries could contribute not only to promote the protection of these elements and their environments, but its diffusion, among which the analysis and the proposal of cultural and landscape itineraries occupies a predominant role.

The new possibilities of reference and location that the current technology offers us, together with the precise knowledge of each tower and the insertion of all of them in the territory, make possible the knowledge by the citizens of these heritage assets in an integral way, facilitating a cultural trip characterized by a greater immersion in the urban and territorial landscape values in which defensive heritage can be linked with tourism (Riguccio, Russo, Scandurra, & Tomaselli, 2015). Thus, the inclusion of these elements in active tourism circuits (cycling, hiking) and in general cultural tourism and ecotourism, can act positively in the knowledge and dissemination of this heritage and the economic capacity of a region.

2 ANALYSIS AND TESTS PERFORMED

As a complement of planimetry obtained by procedures as photogrammetry or terrestrial laser scanning (TLS), complete architectural surveys are being performed as part of the analysis to obtain a global description of construction systems used. These surveys include non-destructive techniques (NDT) as Operational Modal Analysis (OMA) or thermography as well as carbon dating techniques (Binda, Saisi, & Tiraboschi, 2000; Moropoulou, Labropoulos, Delegou, Karoglou, & Bakolas, 2013). Results obtained during surveys and the subsequent analysis performed on the first set of towers bring to light data about general stiffness and the effects of the existing cracks on walls and interior vaults on the global bracing. Moreover, data obtained on NDT provide essential information to evaluate the masonry quality. This empirical information together with the analytical and numerical analysis allows to evaluate the structural safety. In addition, the deep knowledge obtained about the construction system allow to afford the different historical constructive periods on each specific tower identifying and dating also the alterations and add-on. Furthermore, comparison between results obtained for different exemplars also provide knowledge about techniques and construction systems of this important set of medieval defensive architecture and their survival along centuries.

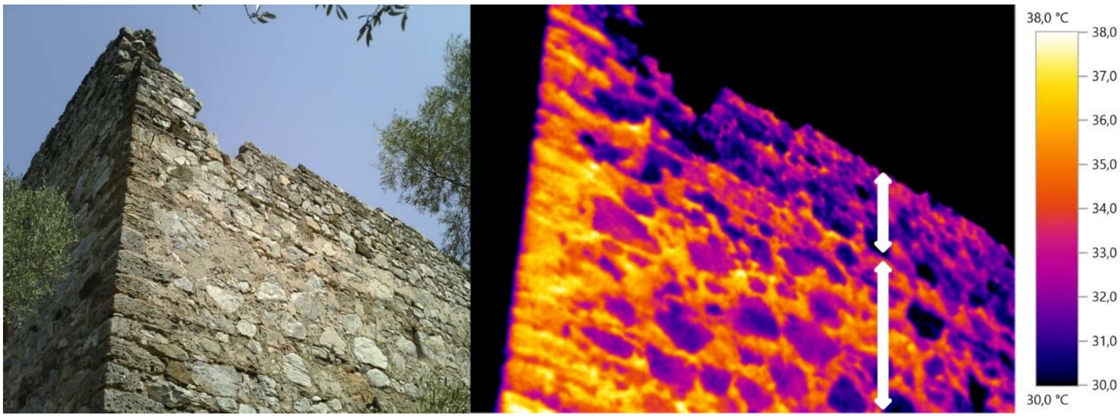

Figure 3. Thermographic analysis of the tower of Campanillas (Malaga) revealing different construction stages and the material distribution of the wall.

3 NON-DESTRUCTIVE TESTING

3.1. Thermographic analysis

In 1965, the first thermographic camera was commercialized to inspect electrical systems. Soon its use was extended for specific applications in the field of construction, especially oriented in the analysis of existing buildings. Thus, its use allows to determine and distinguish between different materials used in the construction; possible hidden elements; identification of damages;

position of structural elements; or location of wet areas and heat losses on thermal bridges (Cañas Guerrero, Martín Ocaña, & González Requena, 2003).
The medieval towers aim of this research are rarely in their original state. Many of them have undergone modifications over time because of their adaptation to new war techniques (artillery) or to be useful for uses different from the original. This procedure have been successfully applied to masonry buildings (Meola, 2007). Using this method to watchtowers, the thermographic analysis allows to identify materials or constructive systems used in the different construction stages (figure 3), as well as the possible existence of hidden elements such as blind openings or ducts not visible on the surface.

1.1*Stiffness measures*

The method of environmental vibration, also known as operational modal analysis (OMA) is used to determine in situ the structural stiffness of the building. Through the performance of a non-destructive test it is possible to determine the fundamental period of vibration of the structure (Espinoza, Canas, Pujades, Caselles, & Mena, 2000). This data, by contrasting with the analytical, will help us to determine the stiffness of the building, revealing both the state of conservation and the overall structural bracing of the building, as well as the stability of specific elements (slabs, walls or vaults).

This method of analysis is based on the natural excitation that a structure suffers subjected to environmental vibrations (traffic, wind, etc.). Obtaining the value for the frequency of vibration in these conditions allows us to know the behaviour of the structure facing them. This environmental vibration excites the building which responds through a certain oscillation. This oscillation frequency will provide us valuable information to determine the degree of bracing of the studied structure. This procedure has proved to be useful for masonry buildings (Ceravolo, Pistone, Fragonara, Massetto, & Abbiati, 2016) and especially for those subjected to dynamic loads as earthquakes (Snoj, Österreicher, & Dolšek, 2013).

This test is performed by an accelerometer, a device capable of measuring small oscillations, especially those not perceived by humans. The data send out by the accelerometer are filtered through a digital analogue converter that, through the appropriate software, can be collected by a laptop. Some of the results of different measures developed are listed in table 2.

Table 2. Natural frequency of some watchtowers measured.

Tower and location	Fundamental Period (s)	Shape
Torre de Montelviche (Vélez-Blanco, Almería)	0.17	Cylindrical
Torre de Agicampe (Loja, Granada)	0.22	Cylindrical
Torre de Urique (Alhaurín el Grande, Málaga)	0.17	Cube-shaped
Torre de Esteril (Benahavís, Málaga)	0.18	Cube-shaped
Torre de Casasola (Estepona, Málaga)	0.24	Cylindrical
Torre de Guadalmansa (Estepona, Málaga)	0.18	Cube-shaped

The natural frequency of a system is directly proportional to its rigidity and inversely proportional to its mass. Consequently, from the measurement of the natural frequency of vibration of the structure subjected to environmental vibrations it is possible to determine its stiffness. A priori, a higher value of the natural frequency would indicate higher stiffness, although this value should be contrasted with the theoretical obtained from the analytical model used to develop the structural analysis.

From results obtained it is possible to highlight the similarity between the fundamental period of the towers with the same typology (cube-shaped or cylindrical).

This allows to clearly differentiate those that even belonging to the same typology present different results. As an example of this, it is possible to remark the tower of Montelviche, located to the east of Nasrid kingdom, on the current border between Almeria and Murcia. Its fundamental period (table 2) is approximately 27% lower than other cylindrical towers. This could indicate this watchtower has constructive characteristics that provide higher stiffness than those located in the provinces of Malaga and Granada.

3.2. Structural analysis

In addition to the non-destructive tests carried out in situ discussed previously, analytical models are being made for each tower to develop its structural analysis (figure 4).

These models, through the use of finite element analysis, allow obtaining the stresses over the walls and vaults that cover the interior spaces (Lourenço, 2002). Besides it is possible to obtain detailed information about the structure as the modal properties. Thus, comparing these analytical models with the results from the operational modal analysis it is possible to estimate the structural stiffness and at the same time to calibrate the accuracy of the model to the structural reality.

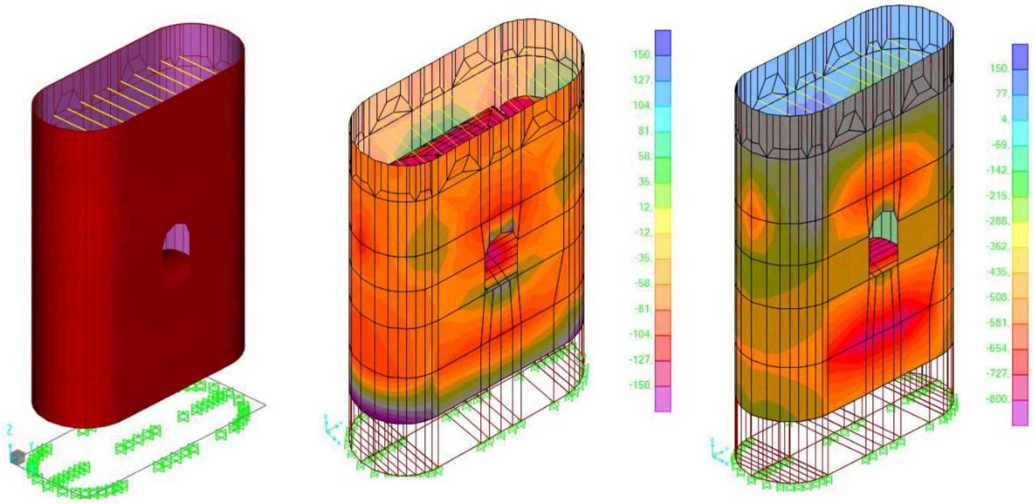

Figure 4. Agicampe watchtower structural analysis. From left to right: analytical model; S11 stress; S22 stress (stresses obtained considering gravity loads)

The structural analysis is revealing those points where the structure is subject to higher stresses. These, in general, coincide with the starting points of the vaults that cover the different spaces where they transmit its thrust to the wall. Therefore, it must be verified the wall has enough thickness to support these thrusts.

In addition, these towers are in the Iberian Peninsula with the highest incidence of earthquakes. The dynamic analysis carried out makes possible to identify the most vulnerable points of these structures, highlighting relevant information must be considered during the restoration process (Valluzzi, 2006). Besides this information allows to make a diagnosis of the possible causes that induced some of the existing damages or even the destruction of some of them.

4 CONCLUSIONS

The group constituted by the towers that controlled the border of the Nasrid kingdom of Granada, although with a common base, each one presents its own characteristics, both at a morphological and constructive level. To ensure its preservation, a survey program has been established to obtain relevant information for its characterisation. Thus, as a complement of planimetry obtained by procedures as photogrammetry or terrestrial laser scanning (TLS), complete architectural surveys using non-destructive techniques are being performed as part of the analysis to obtain a global description of construction systems used. These surveys include a set of non-destructive techniques (NDT) as Operational Modal Analysis (OMA) or thermography as well as carbon dating techniques. Results obtained during surveys and the subsequent analysis performed on the first set of towers bring to light data about general stiffness and the effects of the existing cracks on walls and interior vaults on the global bracing. Moreover, data obtained on NDT provide essential information to evaluate the masonry quality.

This empirical information together with the analytical and numerical analysis allows evaluate the structural safety. In addition, the deep knowledge obtained about the construction system allow to afford the different historical constructive periods on each specific tower identifying and dating also the alterations and add-on. Furthermore, comparison between results obtained for different exemplars also provide knowledge about techniques and construction systems of this important set of medieval defensive architecture and their survival along centuries.

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